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SUBJECT I
SEVEN YEAR PLAN FOR AGRICULTURE – OUTPUT AND BIOWASTE MANAGEMENT

Enhancing Inputs Use Efficiency through Resource Conservation Technologies: Empirical Evidences from Different Agro-Climatic Zones of Uttar Pradesh

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ABSTRACT

Resource conservation technologies (RCTs) are one of the improved practices for crop production, which enhance input use efficiency and reduce the negative consequences of crop production. Out of several options of RCTs, farmers mainly adopt and use zero/reduced tillage and rotavator for land preparation and sowing of wheat crop. The present study is based on primary data and it was collected from eight agro-climatic zones of Uttar Pradesh by using snowball method. Results suggest that, average cost of cultivation of wheat crop was lower and gross and net return from wheat was higher in case of RCTs adopters as compared to non-adopters. The economic benefits due to adoption of RCTs were higher in all the agro-climatic zones of Uttar Pradesh. After adoption of RCTs, diesel consumption, carbon emission and irrigation water use substantially reduced in the study area. The agronomic and net economic water productivity was higher for RCTs adopters as compared to non-adopters. The study further suggests that if farmers of eight agro-climatic zones of Uttar Pradesh allocate 25 per cent their wheat irrigated area under both technologies, the incremental wheat yield benefit and irrigation water saving would be the tune of 12.74 million quintal and 1011.09 MCM, respectively. Furthermore, if farmers of eight agro-climatic zones of Uttar Pradesh allocate 50 per cent their wheat irrigated area in future under both technologies an incremental wheat yield benefit would be 25.47 million quintals and irrigation water saving would be 2022.19 MCM. The allocation of 50 per cent of wheat irrigated area under both the technologies is quite possible after elimination of certain constraints in adoption of RCTs in the study area. The major constraints associated with the adoption of technologies are high cost of machines and non-availability of machines in time and at lower hiring charges. For the adoption of both technologies on large scale, government should provide more subsidies on the purchase of zero-tillage and rotavator machines because the cost of these machines are very high and farmers are unable to purchase them because of poor economic conditions in the study area. It will also help to reduce the hiring cost and availability of machines in time due to increase in number of machines in the study area.

Keywords: Resource conservation technology, Cost of cultivation, Economic benefit, Environmental benefit, Agronomic water Productivity, Net economic water productivity.

JEL: Q15, Q16, Q20, Q42

I

INTRODUCTION

The tillage of agricultural field was practised as old as human civilisation and its first evidence was found dated back 3000 BC in Mesopotamia. After the advent of mechanical power, viz., tractor and water pumps, the farming community gradually

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shifted from animal power to mechanical power for tillage operation and pumping irrigation water. The tragic dust storm in the Mid-western United States in 1930 was a wake-up call to how human interventions in soil management and ploughing led to unsustainable agricultural systems. In 1930, Edward H. Faulkner questioned the utility of intensive tillage in his manuscript called "Ploughman's Folly" (Faulkner, 1943). Since 1930, agricultural scientists were advocating farming community to reduce tillage which leads to minimum use of fossil fuel, reduce soil erosion and reverse loss of soil organic matter by incorporating crop residue into soil. After development of seeding machine during 1940, it made sowing possible without soil tillage (Friedrich *et al*., 2012). The soil erosion, water losses from run-off and soil physical property may be checked by minimum soil disturbance with organic soil cover (Serraj and Siddique, 2012). Many past researchers reported that after adoption of minimum soil tillage the usage of fossil fuel reduced which led to lower emission of carbon dioxide (Kern and Johnson, 1993; West and Marland, 2002; Hobbs and Gupta, 2004; Holland, 2004; Govaerts *et al*. 2009; Singh *et al*. 2010; Singh, 2016a, b; Singh *et al.*, 2016a,b,c; Singh *et al*., 2017a,b).

The resource conservation technologies (RCTs) are one of the improved technologies for crop production. Out of several options of RCTs, farmers are mainly adopting and using zero/reduce tillage and rotavator for land preparation and sowing of wheat crop. Many past researchers in the field of RCTs reported that after adoption of technology, cost of cultivation of wheat crop reduced significantly and net income from wheat crop in different regions of world enhanced as compared to conventional method of wheat cultivation (Laxmi *et al.*, 2007; Kumar *et al.*, 2005; Singh *et al.*, 2011; Pal *et al.*, 2010; Singh and Meena, 2013; Grey *et al*. 1996; Malik *et al*., 2005; Singh, 2016a,b; Singh *et al*., 2016a,b,c; Singh *et al*., 2017a,b). Reduction in use of inputs of wheat crop production and augmentation of crop yield leads to overall betterment of the socio-economic conditions of farmers (Nagarajan *et al*., 2002; Kaur *et al.*, 2012).

Water is one of the most crucial and important inputs that helped farmers to adopt improved agronomic practices for crop production including high yielding variety seeds, chemical fertilisers etc. and cropping intensity to cater to the demand of agricultural produce to feed the fast growing population of different regions of the world, which leads farmers to shift their crop production from subsistence nature of farming to commercial farming. The use of intensive inputs, mechanisations of agriculture and intensive irrigation have contributed to rapid increase in crop production (FAO, 2011). Over the past four decades, groundwater became the main source of growth in irrigated crop production and it accounted for about 60 per cent of the total irrigated area in India. It is estimated that over 70 per cent of India's foodgrain production comes from the irrigated agriculture (Gandhi and Namboodiri, 2009). The negative consequences of uncontrolled water withdrawal and use are that many Indian regions are facing absolute water scarcity and physical water scarcity has threatened the survival of human beings as 80 per cent of total water withdrawal is being used for crop production.Looking into the constraints of physical water availability, researchers, and policymakers are searching for different options of crop production to minimise irrigation water use for crop production. The present studyaimsat enhancing inputs use efficiency through RCTs in different agro-climatic zones of Uttar Pradesh. The objectives of the study are: (a) to estimate the cost of cultivation of wheat crop under RCTs and conventional method; (b) to study the economic and environmental benefits of RCTs; (c) to find out the irrigation water use, agronomic and net economic water productivity of wheat crop under RCTs and conventional method in different agro-climatic zones of Uttar Pradesh and (d) to examine resource use efficiency in different agro-climatic zones of Uttar Pradesh.

II

DATA AND ANALYTICAL TOOLS

2.1 *Data Used*

The study is based on the primary and secondary data. Primary data was collected through personal interview using pre-tested schedule for the agricultural year 2016-17. Uttar Pradesh is divided into nine agro-climatic zones. Out of nine agro-climatic zones, eight agro-climatic zones were selected purposively on the basis of highest adoption of Resource Conservation Technologies (RCTs). From each agro-climatic zone, one district was selected purposively. From each selected district, two development blocks were purposively selected on the basis of one having highest adoption of RCTs and another having lowest adoption of RCTs. From each selected development block, one village or cluster of villages was selected purposively for primary data collection. From each village, 10 RCTs adopters and 10 RCTs non-adopters were selected using snowball sampling method. The total sample size was 320 consisting of 160 RCTs adopters and 160 RCTs non-adopters (Table 1).

2.2 *Analytical Tools*

2.2.1*Cost of Cultivation*

The cost of cultivation for wheat crop was estimated by using the costs concept suggested by Commission for Agricultural Costs and Prices (CACP). Per hectare incremental cost of cultivation (Δ_{CC}) for wheat crop was estimated by using following method:

$$\Delta_{CC} = \Phi_{RCT} - \Phi_{C}$$

whereΔ_{CC} is the incremental cost of cultivation (Rs./ha), Φ_{RCT} is the total inputs cost used by the RCTs adopters (Rs./ha) and Φ_{C} is total inputs cost used by the RCTs non-adopters (Rs./ha).

TABLE 1. NAME OF SELECTED DISTRICT, BLOCKS AND VILLAGES
FOR PRIMARY DATA COLLECTION

Name of agro-climatic zones (1)	Name of selected districts (2)	Name of blocks (3)	Name of village (4)	Number of respondents	
				RCTs adopters (5)	RCTs non-adopters (6)
1. Vindhyan	1. Mirzapur	1.Narayanpur	Bhurkura	10	10
		2. Jamalpur	Pirkhir	10	10
2. Central plain	2. Kaushambi	1. Newada	KadirpurNewada	10	10
		2. Muratganj	Mohnapur	10	10
3. Western plain	3. Ghaziabad	1.Rajapur	Matiyala	10	10
		2. Bhojpur	Tahlata	10	10
4. North-eastern plain	4. Gorakhpur	1. Bhatahata	Pokharbhinda	10	10
		2.Brahmpur	Belwa	10	10
5. Eastern plain	5. Chandauli	1. Barhani	Barhani	10	10
		2. Sahebganj	Khilchi	10	10
6. Mid-western plain	6. Bareilly	1. Nawabganj	Vakaniya	10	10
		2. VithariChainpur	Sisaiya	10	10
7. Tarai and Bhabar	7. Bahraich	1.Risia	PatanaGhishiyari	10	10
		2. Shivapur	Itaha	10	10
8. South-western plain	8. Etah	1. NidhauliKalan	Gerhana	10	10
		2. Punehra	Awagarh	10	10
Total	8	16	16	160	160

2.2.2 *Economic Benefits*

Economic benefits of RCTs are worked out using economic surplus model as suggested by Alston *et al.* (1995). The model is given below:

$$\Delta\, CS = P_0 Q_0 Z\, (1 + 0.5Z_{\eta})$$
$$\Delta\, PS = P_0 Q_0 (K - Z)\, (1 + 0.5Z_{\eta})$$
$$\Delta\, TS = P_0 Q_0 K\, (1 + 0.5Z_{\eta})$$

where:

P_0 = Base price of the commodity
Q_0 = Base Quantity
η = Absolute value of the price elasticity of demand
Z = K ε/ (ε+ η); or the proportionate price reduction in the market where ε is the elasticity of supply
K = Proportionate reduction in cost of production
ΔCS= Change in consumer surplus
ΔPS= Change in producer surplus
ΔTS= Change in total economic surplus

2.2.3 *Reduction in Carbon Emission*

Environmental benefits realised by adoption of RCTs were quantified. Generally these benefits are reduction in carbon emission and improvement of carbon/organic content through residue management in soil. To find out the carbon emission following methodology was adopted:

1 litre diesel = 2.6 kg of CO_2 (Jat *et al*., 2006)

1 kg CO_2 = 0.27 kg of carbon (Paustian *et al*., 2006)

2.2.4 *Irrigation Water Use*

For quantification of irrigation water used for wheat production following equation was used (Singh, 2004):

$$\theta_{(m^3)} = I_n x H_{pi} x P_d$$

where, $\theta_{(m^3)}$is total irrigation water used for wheat production measured in m^3/ha, I_n is number of irrigation given to wheat crop during crop period; H_{pi} is the hours required to provide one irrigation, P_d is the pump discharge rate measured as m^3/hour.

2.2.5 *Pump Discharge Rate*

Farmers of the study area were using groundwater for irrigating wheat crop. For the quantification of irrigation water use following formula was used (Singh, 2004):

$$Pd_{(m^3/Hr)} = \frac{HP * 75 * Pe}{1000 * DW} x\ 3600$$

Where *Pd* is pump discharge rate measured in m^3 per hour; *HP* is the pump capacity; *Pe* is the pump efficiency; and *DW* is depth to water level plus head of delivery pipe measured in meter.

2.2.6 *Physical Water Productivity*

Physical water productivity (kg/m^3) for wheat crop was estimated using the data on crop yield and the estimated volume of irrigation water applied to wheat crop. The physical water productivity of wheat crop was estimated through following equation (Singh, 2004):

$$WP_{(kg/m^3)} = \frac{Q_{(kg)}}{\theta_{(m^3)}}$$

Where *WP* is the physical water productivity of wheat crop measured as kg/m^3, $Q_{(kg)}$ is wheat yield measured in kg per hectare and $\theta_{(m^3)}$ is the total irrigation water used for wheat crop during entire crop period measured in m^3/ha.

2.2.7 *Net Economic Water Productivity*

For estimation of net economic water productivity (Rs./m^3), data related to the crop yield (both main and by-product), farm harvest price and total input costs were used. The combined physical and economic water productivity for wheat production was estimated using following equation (Singh, 2004):

$$WP_{(\text{Rs.}/m^3)} = \frac{NI_{(\text{Rs})}}{\theta_{(m^3)}}$$

where, $WP_{(\text{Rs.}/m^3)}$ is the net combined physical and economic water productivity (Rs./m^3); $NI_{(\text{Rs.})}$ is the net income received from wheat crop (Rs./ha) and and$\theta_{(m^3)}$ is the total irrigation water used during entire period of wheat crop measured in m^3/ha.

2.2.8 *Production Function*

The Cobb-Douglas production function was used to find out the resource use efficiency in the study area. In production function, dummy variable was introduced to capture the impact of RCTs on value of output in wheat crop in case of adopters and non-adopters. Another dummy variable was used to capture whether benefits of technology are accruing to the marginal and small farmers. The following equation was used to estimate the production function:

$$Y = a\, X_1^{b1} X_2^{b2} X_3^{b3} X_4^{b4} X_5^{b5} X_6^{b6} X_7^{b7} e^{\mu}$$

where:

Y = Value of output (Rs. per hectare)
a = Constant
X_1 = Cost of human labour (Rs. per hectare)
X_2 = Cost of machine labour (Rs. per hectare)
X_3 = Cost of seed (Rs. per hectare)
X_4 = Cost of fertiliser (Rs. per hectare)
X_5 = Cost of irrigation (Rs. per hectare)
X_6 = Dummy variable for RCTs (adopter = 1 and Non-adopters = 0)
X_7 = Dummy variable for land holding size ($\leq$ 2 hectare = 0; >2 ha = 1)
e^{μ} = Error term
b_1 to b_7 = Regression coefficient of concerned variables

2.2.9 *Test of Significance of the Deference between Two Means of Key Variables*

To compare the difference between two means of key variables (cost of cultivation, yield and carbon emission) of adopters and non-adopters, t-test was used as follows:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$

where:

$\overline{X}_1$ = Mean of key variables in case of adopters

$\overline{X}_2$ = Mean of key variables in case of non-adopters

S_1 = Standard deviation of key variables for adopters

S_2 = Standard deviation of key variables for non-adopters

n_1 = Sample size of adopters

n_2 = Sample size of non-adopters

III

RESULTS AND DISCUSSION

3.1 *Socio-Economic Profile of the Sample Farmers*

The average age of RCTs adopters was lower than the RCTs non-adopters in all the agro-climatic zones of Uttar Pradesh except Vindhyan, North-eastern plain and Tarai and Bhabar agro-climatic zones. The farming experience of RCTs adopters was higher as compared to RCTs non-adopters in all the agro-climatic zones except Central plain, Eastern plain and Mid-western plain zones. As for as education level is concerned, all the RCTs adopters were found to be well educated as compared to RCTs non-adopters. Average family size of adopters was estimated to be higher as compared to RCTs non-adopters in all agro-climatic zones except in Vindhyan and Tarai and Bhabar agro-climatic zones. The average number of children (< 18 years) was higher in case of adopters as compared to non-adopters. The average size of land holding was found to be higher for adopters as compared to RCTs non-adopters (Table 2). The area under leased in land was found to be more in case of adopters as compared to non-adopters (Table 2).

3.2 *Technologies Adopted by Sample Farmers*

The options of resource conservation technologies (RCTs) are zero/reduce tillage, laser land levelling, direct seeding, bed planting, surface seeding, paired row, control traffic, unpuddled rice transplanting, leaf colour chart and brown manuring. Out of these options, the most common options adopted by the sample farmers in the study area for wheat cultivation was zero/reduce tillage and rotavator (Table 3). The farmers of Vindhyan region, Central plain, Western plain, North-eastern plain and Eastern plain agro-climatic zones were using zero/reduce tillage for sowing of wheat crop just after harvesting of paddy crop, whereas in case of mid-western plain, Tarai and Bhabar and South-western plain agro-climatic zones, farmers were using rotavator for land preparation and sowing of wheat crop.

TABLE 2. SOCIO-ECONOMIC PROFILE OF SAMPLE FARMERS

	Zero/reduce tillage					Rotavator tillage		
Particulars (1)	Vindhyan (2)	Central plain (3)	Western plain (4)	North-eastern Plain (5)	Eastern plain (6)	Mid-western plain (7)	Tarai and Bhabar (8)	South-western plain (9)
				Adopters				
1. Age of the farmers (year)	52.60	50.40	52.15	51.95	50.40	48.95	49.30	50.15
2. Farming experience (year)	31.30	29.25	27.55	31.90	20.90	30.00	30.25	31.70
3. Years of schooling	12.60	10.30	13.20	10.75	13.45	9.40	10.00	10.70
4. Family size (No.)	6.95	9.90	10.15	11.10	9.80	8.60	10.55	11.45
a. Children (< 18 years)	1.20	3.35	4.35	3.90	3.95	3.20	4.55	4.25
b. Adult (18-50 years)	3.80	4.85	3.75	5.30	4.55	4.05	4.30	5.30
c. Old (> 50 years)	1.95	1.70	2.10	1.95	1.45	1.42	1.70	1.90
5. Land holding size (ha)	4.77	3.02	6.09	1.80	4.67	1.68	2.22	2.83
6. Leased in land (ha)	1.03	0.25	0.68	0.06	0.12	0.32	0.03	0.24
				Non-adopters				
1. Age of the farmers (year)	50.75	52.20	53.15	49.65	59.80	53.10	46.60	53.60
2. Farming experience (year)	29.55	31.40	27.00	29.40	40.90	34.20	25.70	31.20
3. Year of schooling	10.90	8.70	13.30	8.75	11.05	8.65	7.60	10.40
4. Family size (No.)	7.70	8.65	9.85	9.05	8.35	8.50	11.10	9.10
a. Children (< 18 years)	2.00	3.35	3.90	3.25	2.75	2.45	4.60	3.20
b. Adult (18-50 years)	4.35	3.95	3.75	4.65	3.80	4.60	4.50	4.00
c. Old (> 50 years)	1.35	1.35	2.20	1.75	1.80	1.45	2.00	1.95
5. Land holding size (ha)	2.90	2.33	4.76	1.16	3.55	2.17	1.37	2.35
6. Leased in land (ha)	0.19	0.20	0.42	-	0.13	0.07	0.10	0.22

TABLE 3. TYPE OF RCTs ADOPTED BY SAMPLE FARMERS FOR WHEAT CROP

Name of the agro-climatic zones (1)	Name of the districts (2)	Types of RCTs used (3)	Sample size (4)
1. Vindhyan region	Mirzapur	Zero/reduce tillage	20
2. Central plain	Kaushambi	Zero/reduce tillage	20
3. Western pain	Ghaziabad	Zero/reduce tillage	20
4. North-eastern plain	Gorakhpur	Zero/reduce tillage	20
5. Eastern plain	Chandauli	Zero/reduce tillage	20
6. Mid-western plain	Bareilly	Rotavator	20
7. Tarai and Bhabar	Bahraich	Rotavator	20
8. South-western plain	Etah	Rotavator	20

In case of zero-tillage/reduce tillage, farmers in the study were using zero-tillage machine just after harvesting of paddy crop for sowing of wheat crop without land preparation and using residual moisture of paddy field. In case of rotavator, farmers are ploughing their field after harvesting of paddy crop and they broadcast wheat seed and mix wheat seed into the soil with the help of rotavator. In case of conventional method, farmers were ploughing their field three to four times after harvesting of paddy crop, broadcasting wheat seed and again using one or two ploughing to mix wheat seed into the soil.

3.3 *Cost of Cultivation and Wheat Yield*

In most of the agro-climatic zones of Uttar Pradesh, per hectare average cost of cultivation in case of RCTs adopters was lower as compared to non-adopters. In case of zero/reduced tillage, highest reduction in cost of cultivation was found in Vindhyan region (Rs.7077) and lowest reduction was observed in North-eastern plain with Rs. 4151 as compared to non-adopters (Table 4). In the Eastern plain, cost of cultivation for zero/reduce tillage adopters was higher as compared to non-adopters due to adoption of high yielding varieties of wheat seed. In case of rotavator, reduction in per hectare cost of cultivation was highest in Tarai and Bhabar agro-climatic zone with Rs.11527, whereas it was lowest in South-western plain with Rs.2309.04. In case of Mid-western plain, per hectare cost of cultivation was higher for rotavator adopters as compared to rotavator non-adopters. The difference in cost of cultivation was found to be significant in Vindhyan, Central plain and Tarai and Bhabar agro-climatic zones.

TABLE 4. COST OF CULTIVATION AND YIELD OF WHEAT CROP UNDER DIFFERENT RCTS

Name of the agro-climatic zones (1)	Cost of cultivation (Rs./ha)		Difference in cost of cultivation (Rs./ha) (4)	Crop yield (qtls./ha)		Incremental yield benefit (qtls./ha) (7)
	RCTs adopters (2)	RCTs non-adopters (3)		RCTs adopters (5)	RCTs non-adopters (6)	
			Zero/Reduce Tillage			
1. Vindhyan	51361.65	58438.73	7077.08** (- 2100)	35.59	32.98	2.61* (7.615)
2. Central plain	39213.50	45744.02	6530.52* (-5.443)	35.45	29.50	5.95* (2.818)
3. Western plain	51315.21	57269.99	5954.78 (-0.971)	49.88	43.67	6.21* (6.760)
4. North-eastern plain	48459.35	52609.86	4150.51 (-0.921)	35.75	30.93	4.82* (3.756)
5. Eastern plain	48695.03	47320.56	-1374.47 (0.195)	32.01	27.16	4.85* (11.259)
			Rotavator Tillage			
6. Mid-western plain	39835.19	39027.52	-807.67 (-1.348)	44.08	35.48	8.60* (4.983)
7. Tarai and Bhabar	45666.83	57194.71	11527.88*** (-1.745)	44.04	36.92	7.12* (4.182)
8. South-western plain	48581.62	50890.66	2309.04 (0.087)	45.36	37.21	8.15* (3.376)

Figures in parentheses indicate t values and degree of freedom 38 in each case.
*,** and*** Significant at 1, 5 and 10 per cent level, respectively.

After adoption of RCTs for wheat cultivation, farmers were getting higher wheat yield as compared to RCTs non-adopters. In case of zero/reduced tillage, per hectare highest incremental wheat yield over conventional method was observed for Western plain (6.21 qtls.) and lowest for Vindhyan agro-climatic zone with 2.61 quintals. In case of rotavator, per hectare highest incremental wheat yield was observed for mid-western plain (8.6 qtls) and lowest in case of Tarai and Bhabar agro-climatic zone with 7.12 quintals over conventional method. The difference in mean yield of wheat was found to be significant in all agro-climatic zones.

Per hectare higher wheat yield obtained by RCTs adopters was due to incorporation of crop residues into agricultural field, which has positive and significant impact on soil physical, chemical and biological properties. Mixing of crop residue enhances soil organic carbon content, increases N, P, K, prevents nitrogen leaching in deeper soil, augments biodiversity in the soil, moderates soil temperature, reduces evaporation, improves biological activity and provides more conducive environment for root development, which leads to augmentation of wheat yield (Singh *et al*. 2005; Sidhu and Beri, 2005; Misra *et al*., 1996; Singh and Meena, 2013).

3.4 *Gross and Net Income from Wheat*

The RCTs reduce the use of human and mechanical labour. It advances in sowing time, helps in reduction in fossil fuel and farm power use for different agricultural operations which leads to reduction in cost of cultivation as compared to conventional method (Singh and Sharma, 2005; Laxmi and Mishra, 2007). The reduction in cost of cultivation varies with agro-climatic regions, technology adopted by farmers and crops grown under RCTs (Sarwar and Goheer, 2007; Sikka *et al*., 2005; Grover *et al*., 2005).

After adoption of RCTs in the study area, the sample farmers received higher gross and net income as compared to RCTs non-adopters. It is due to the lower use of inputs in wheat cultivation and higher wheat production (both main and by-products). In case of zero/reduce tillage adopters, per hectare highest incremental gross income was observed in Western plain (Rs.11118) and lowest in Vindhyan agro-climatic zone with Rs.4692 over conventional method of wheat cultivation. In case of rotavator, highest per hectare gross incremental benefit was observed in South-western plain (Rs.17139.91) and lowest in Tarai and Bhabar agro-climatic zone (Rs. 13244.81) over conventional method of wheat cultivation (Table 5).

TABLE 5. GROSS AND NET INCOME FROM WHEAT CROP UNDER DIFFERENT RCTs

Name of agro-climatic zones (1)	Gross income (Rs./ha) RCTs adopters (2)	Gross income (Rs./ha) RCTs non-adopters (3)	Incremental gross income (Rs./ha) (4)	Net income (Rs./ha) RCTs adopters (5)	Net income (Rs./ha) RCTs non-adopters (6)	Incremental net income (Rs./ha) (7)
			Zero/Reduce Tillage			
1. Vindhyan	66153.55	61461.97	4691.58	14791.90	3023.24	11768.66
2. Central plain	56051.10	48168.97	7882.13	16837.60	2424.94	14412.66
3. Western plain	89335.65	78217.56	11118.09	38020.44	20947.57	17072.87
4. North-eastern plain	60948.79	53709.01	7239.78	12489.44	1099.15	11390.29
5. Eastern plain	57984.57	49019.87	8964.70	9289.53	1699.30	7590.23
			Rotavator Tillage			
6. Mid-western plain	71684.99	57600.71	14084.28	31849.79	18573.19	13276.60
7. Tarai and Bhabar	81855.99	68611.18	13244.81	36189.16	11416.47	24772.69
8. South-western plain	94300.95	77139.91	17139.91	45719.32	26249.25	19470.07

Per hectare net incremental income received by zero/reduce tillage adopters was highest in Western plain (Rs.17073) and lowest in Eastern plain (Rs.7590.23) agro-climatic zones over zero-tillage non-adopters. In case of rotavator adopters per hectare highest net incremental benefit was received in Tarai and Bhabar (Rs.24773) and lowest in mid-western plain agro-climatic zone with Rs.13276.60 over rotavator non-adopters (Table 5).

3.5 *Economic Benefits of RCTs Adoption*

The economic benefits of RCTs are reduction in cost of human labour, cost of machine labour, cost of seed, cost of fertiliser, cost of pesticide, cost of irrigation, cost of harvesting, increase in wheat yield (both main and by-products) and saving of diesel cost. Per hectare economic benefits due to adoption of zero/reduce tillage in the study area were estimated and it was found to be highest in Western plain (Rs. 20537.43), whereas it was lowest in Eastern plain with Rs.10426.91 (Table 6). In case of rotavator adopters, per hectare economic benefit was found to be highest in Tarai and Bhabar agro-climatic zone with Rs.26130.17, whereas it was lowest in Mid-western plain with Rs.18701.06 (Table 6).

TABLE 6. ECONOMIC BENEFITS OF RCTs

(*Rs./ha*)

	Name of the agro-climatic zones of Uttar Pradesh							
Economic benefits due to reduction in (1)	Vindhyan (2)	Central plain (3)	Western plain (4)	North-eastern plain (5)	Eastern plain (6)	Mid-western plain (7)	Tarai and Bhabar (8)	South-western plain (9)
	Zero/Reduce Tillage					Rotavator Tillage		
Cost of human labour	1363.65	783.06	1378.94	131.20	548.58	355.86	50.78	-32.56
Cost of machine labour	3042.88	3199.42	3408.12	2504.74	1458.11	2954.00	2931.56	1461.95
Cost of seed	893.73	681.96	674.07	645.05	-309.69	629.54	109.27	82.14
Cost of fertiliser	556.24	108.05	411.61	425.64	-1507.42	49.35	1391.72	-384.19
Cost of pesticide	16.75	2.50	27.50	-12.50	25.00	0.00	3.75	0.00
Cost of irrigation	568.98	848.57	1615.37	663.48	593.02	1195.12	2332.22	1840.23
Cost of harvesting	129.87	112.53	29.26	-479.44	10.90	-2191.78	3167.68	68.11
Due to yield benefits	4691.59	7882.13	11118.09	7239.78	8964.70	14084.27	13244.81	17161.04
Due to diesel saving*	1748.41	1564.16	1874.47	1422.91	643.72	1624.70	2898.37	536.05
Total	13012.10	15182.37	20537.43	12580.85	10426.91	18701.06	26130.17	20732.76

*Cost of diesel is Rs.55 per litre.

3.6 *Reduction in Carbon Emission*

Many past researchers reported that after adoption of RCTs, the air pollution reduces and mitigate environmental degradation by management of crop residue and carbon sequestration (Akhtar, 2006; Laxmi and Mishra, 2007). RCTs reduce diesel consumption for land preparation and sowing of wheat crop which leads to reduction in carbon emission (Pal *et al*., 2010). One litre diesel burning generates 2.6 kg of CO_2 (Jat *et al*., 2006) and one kg CO_2 is equal to 0.27 kg of carbon (Paustian *et al*., 2006). It is clearly observed from Table 7 that after adoption of RCTs, diesel consumption for land preparation, sowing of wheat crop and groundwater pumping using diesel operated pumps substantially reduced, which leads to reduction in the carbon emission.

In case of zero/reduce tillage, reduction in diesel consumption per hectare was highest in Western plain (34.08 lts) and lowest in Eastern plain with 11.70 lts as compared to non-adopters. After adoption of zero/reduce tillage, per hectare carbon emission reduced from wheat cultivation in Western plain with 23.92 kg which was highest and lowest in Eastern plain region with 8.22 kg as compared to zero/reduce tillage non-adopters.

TABLE 7.CARBON EMISSION FROM WHEAT CROP

(*per ha*)

	RCTs adopters		RCTs non-adopters		Reduction in	
Name of the agro-climatic zones (1)	Diesel use (lts) (2)	Carbon emission (kgs) (3)	Diesel use (lts) (4)	Carbon emission (kgs) (5)	Diesel use (lts) (6)	Carbon emission (kgs) (7)
			Zero/Reduce Tillage			
1. Vindhyan	64.87	45.55	96.67	67.86	31.80	22.31* (-3.354)
2. Central plain	8.25	6.21	37.29	26.18	29.04	19.97* (-3.962)
3. Western plain	25.07	17.60	59.15	41.52	34.08	23.92 (-0.388)
4. North-eastern plain	57.78	52.41	83.09	71.08	25.31	18.67* (-4.983)
5. Eastern plain	15.00	10.53	26.70	18.75	11.70	8.22* (-6.469)
			Rotavator Tillage			
6. Mid-western plain	103.39	72.58	146.47	102.83	43.08	30.25*** (-1.968)
7. Tarai and Bhabar	85.50	60.02	138.68	97.35	53.18	37.33* (-8.710)
8. South-western plain	105.01	73.72	127.22	89.30	22.21	15.58*** (-1.759)

Figures in parentheses indicate t values and degree of freedom 38 in each case.
*,** and***: Significant at 1, 5 and 10 per cent level, respectively.

In case of rotavator, per hectare reduction in diesel consumption was highest in Tarai and Bhabar (53.18 lts) and lowest in South-western plain as compared to non-adopters (Table 7). Per hectare reduction in carbon emission was maximum in Tarai and Bhabar agro-climatic zone with 37.33 kg and lowest in South-western region with 15.58 kg as compared to rotavator non-adopters.The difference in mean value of carbon emission was found to be significant in all the agro-climatic zones

3.7 *Irrigation Water Use*

Past researchers reported that, RCTs have enabled farmers to sow their wheat crop just after paddy harvesting without any pre-sowing irrigation and it will further reduce the irrigation water in subsequent irrigation (Hobbs *et al*., 2000; Malik *et al*., 2005; Akhtar, 2006; Pal *et al.*, 2010). Irrigation water used during entire period of wheat cultivation by sample farmers in the study area suggests that RCTs adopters were using less irrigation water as compared to RCTs non-adopters in different agro-climatic zones of Uttar Pradesh (Table 8).

TABLE 8. IRRIGATION WATER USE

Name of the agro-climatic zones (1)	Irrigation water use (m^3/ha) RCTs adopters (2)	RCTs non-adopters (3)	Reduction in irrigation water use (m^3/ha) (4)
		Zero/Reduced Tillage	
1. Vindhyan	700.57	772.26	71.69
2. Central plain	1747.17	1982.75	235.58
3. Western plain	2235.44	3582.95	1347.51
4. North-eastern plain	1656.73	1783.48	126.75
5. Eastern plain	1740.27	1980.75	240.48
		Rotavator Tillage	
6. Mid-western plain	2628.75	3218.91	590.16
7. Tarai and Bhabar	4336.17	5707.25	1371.08
8. South-western plain	3769.88	4716.27	946.39

In case of zero/reduced tillage adopters, per hectare irrigation water used was highest in Western plain (2235.44 m^3/ha) and lowest in Vindhyan agro-climatic zone with 700.57 m^3/ha, whereas in case of non-adopters it was highest in Western plain (3582.95 m^3/ha) and lowest in Vindhyan agro-climatic zone with 772.26 m^3/ha per hectare respectively (Table 8). After adoption of zero/reduce tillage for wheat cultivation, per hectare irrigation water saved was highest in Western plain to the tune of 1347.51 m^3/ha and lowest in Vindhyan zone with 71.69 m^3/ha.

In case of rotavator adopters, per hectare irrigation water used was highest for wheat cultivation in the study area which was estimated to be 4336.17 m^3/ha and lowest (2628.75 m^3/ha) in Tarai and Bhabar and Mid-western plain respectively, whereas in case of non-adopters, it was highest 5707.25 m^3/haand lowest (3218.91 m^3/ha) for Tarai and Bhabar and mid-western plain respectively (Table 8). After the adoption of rotavator, highest irrigation water saved per hectare was reported to be the highest in Tarai and Bhabar agro-climatic zone with 1371.08 m^3/ha and lowest in mid-western plain with 590.16 m^3/ha.

3.8 *Agronomic and Net Economic Water Productivity*

The agronomic water productivity (kg/m^3) and net economic water productivity (Rs./m^3) was estimated for RCTs adopter and non-adopters for different agro-climatic zones of Uttar Pradesh. In case of zero/reduce tillage adopters, highest agronomic water productivity was observed in Vindhyan agro-climatic zone (5.08 kg/m^3) and lowest in Eastern plain (1.84 kg/m^3), whereas in case of non-adopters it was highest in Vindhyan agro-climatic zone (4.27 kg/m^3) and lowest in Western plain (1.22 kg/m^3). In case of rotavator adopters, highest agronomic water productivity was observed for mid-western plain and lowest in Tarai and Bhabar agro-climatic zone with 1.68 and 1.02 kg/m^3 respectively, whereas in case of non-adopters it was highest in Mid-western plain (1.10 kg/m^3) and lowest in Tarai and Bhabar agro-climatic zone with 0.65 kg/m^3 (Table 9).

TABLE 9. AGRONOMIC AND NET ECONOMIC WATER PRODUCTIVITY

Name of the agro-climatic zones (1)	Agronomic water productivity (kg/m^3) RCTs adopters (2)	Agronomic water productivity (kg/m^3) RCTs non-adopters (3)	Incremental agronomic water productivity (kg/m^3) (4)	Net economic water productivity (Rs./m^3) RCTs adopters (5)	Net economic water productivity (Rs./m^3) RCTs non-adopters (6)	Incremental net economic water productivity (Rs./m^3) (7)
Zero/Reduce tillage						
1. Vindhyan	5.08	4.27	0.81	21.11	3.91	17.2
2. Central plain	2.03	1.49	0.54	9.64	1.22	8.42
3. Western plain	2.23	1.22	1.01	17.01	5.85	11.16
4. North-eastern plain	2.16	1.73	0.43	7.54	0.62	6.92
5. Eastern plain	1.84	1.37	0.47	7.88	3.03	4.85
Rotavator tillage						
6. Mid-western plain	1.68	1.10	0.58	12.12	5.77	6.35
7. Tarai and Bhabar	1.02	0.65	0.37	8.35	2.00	6.35
8. South-western plain	1.20	0.79	0.41	12.13	5.57	6.56

Net economic water productivity (Rs./m^3) in wheat crop for different agro-climatic zones for RCTs adopters and non-adopters were estimated. In case of zero-tillage adopters, the highest net economic water productivity was observed in Vindhyan agro-climatic zone (Rs.21.11/m^3) and lowest in North-eastern plain climatic zone (Rs.7.54/m^3). In case of non-adopters, highest net economic water productivity was found in Western-plain and lowest in North-eastern plain agro-climatic zone with Rs.5.85 and Rs.0.62 per m^3 respectively. In case of rotavator adopters, the highest net economic water productivity was found in South-western plain and lowest in Tarai and Bhabar agro-climatic zone. In case of non-adopters, the highest net economic water productivity was observed in Mid-western plain and lowest in Tarai and Bhabar agro-climatic zone (Table 9).

3.9 *Impact of RCTs on Wheat Yield and Irrigation Water Use Under Different Scenarios*

Total wheat area in all eight agro-climatic zones under study was 8.50 million hectares. Out of which 6.35 million hectare area was irrigated. If 6.35 million hectares wheat area is irrigated using conventional method, then total irrigation water requirement was 22873.31 million cubic meters (MCM). Out of total wheat irrigated area, 4.75 million hectare area was under wheat cultivation for five agro-climatic zones, viz., Vindhyan, Central plain, Western plain, North-eastern plain and Eastern plain and 1.60 million hectare irrigated area for three agro-climatic zone, viz., Mid-western plain, Tarai and Bhabar and South-western plain (Table 10).

TABLE 10. IRRIGATED AREA, IRRIGATION WATER USE AND WHEAT YIELD BENEFIT

			25 per cent area under RCTs		50 per cent area under RCTs	
Name of the agro-climatic zones (1)	Irrigated area in the region (ha) (2)	Irrigation water use under conventional method (mcm) (3)	Incremental yield benefit (qts) (4)	Reduction in irrigation water use (mcm) (5)	Incremental yield benefit (qts) (6)	Reduction in irrigation water use (mcm) (7)
Zero/reduce tillage						
1. Vindhyan	201707	155.77	131614	3.62	2632273	7.23
2. Central plain	2320609	4601.19	3451907	136.67	6903813	273.34
3. Western plain	509532	1825.63	791049	171.65	1582097	343.30
4. North-eastern plain	1299227	2317.15	1565569	41.17	3131138	82.34
5. Eastern plain	423071	3351.99	2051896	101.74	4103793	203.48
Sub-Total	4754146	12251.73	7992035	454.85	15984068	909.69
Rotavator tillage						
6. Mid-western plain	745781	2400.60	1603429	110.03	3206858	220.07
7. Tarai and Bhabar	598653	3416.66	1065602	205.20	2131204	410.40
8. South western plain	254667	4804.32	2075538	241.01	4151076	482.03
Sub-Total	1599101	10621.58	4744569	556.24	9489138	1112.50
Grand Total	6353247	22873.31	12736604	1011.09	25473206	2022.19

Based on the primary data for irrigation water use in wheat cultivation under zero/reduce tillage and rotavator, two scenarios were considered. Under first scenario, it was assumed that 25 per cent of 4.75 and 1.60 million hectare wheat area was put under the zero/reduce tillage and rotavator respectively. The results suggest that after putting 25 per cent wheat area under RCTs, the incremental yield benefit from zero/reduce tillage and rotavator would be 7.99 and 4.75 million quintal respectively and irrigation water saving would be 454.85 and 556.24.23 MCM for zero/reduce tillage and rotavator, respectively. Total wheat yield benefits and irrigation water saving from eight agro-climatic zones due to allocation of 25 per cent area under RCTs would be 12.74 million quintals and 1011.09 MCM irrigation water saving (Table 10).

Under second scenario, it was assumed that 50 per cent of 4.75 and 1.60 million hectares wheat area was put under the zero/reduce tillage and rotavator. Results suggests that after putting 50 per cent wheat area under zero/reduce tillage and rotavator, the incremental wheat yield benefit would be 15.98 and 9.49 million quintals respectively and irrigation water saving would be 909.69 and 1112.50 MCM for zero-tillage and rotavator respectively. Total yield benefit of wheat due to allocation of 50 per cent area under RCTs, incremental wheat yield would be 25.47 million quintals and irrigation water saving would be 2022.19 MCM.

3.10 *Production Function*

In Vindhyan agro-climatic zone, the regression coefficient attached to seed turned out to be negative and significant which indicates excessive use of this resource. This implies that one per cent increase in cost of seed would bring a decline in the gross return by 0.339 per cent keeping the other variable resources considered in the equation constant at their geometric mean level (Table 11). The coefficient of dummy variable for land holding size was found positive and significant at 10 per cent level which suggests that as land holding size increase there is chance for adoption of zero/reduce tillage in the study area.

TABLE 11.REGRESSION COEFFICIENT

	Zero/Reduce tillage					Rotavatortillage		
Particulars (1)	Vindhyan (2)	Central plain (3)	Western plain (4)	North-eastern plain (5)	Eastern plain (6)	Mid-western plain (7)	TaraiandBhabar (8)	South-western plain (9)
Constant	16.292*	6.840**	11.926*	9.001*	5.149*	13.133*	7.015*	10.858*
Human labour (Rs.)	0.044	-0.080	-0.037	0.105	-0.198***	-0.044	0.287	0.637*
Machine labour (Rs.)	-0.115	-0.004	0.014	-0.046	0.267***	-0.004	-0.057	-0.341**
Seed (Rs.)	-0.339***	0.638*	-0.085	0.031	0.138*	-0.223	0.072	-0.229***
Manure and fertiliser (Rs.)	-0.085	0.023	0.073	0.100	0.181*	0.074	0.105	0.045
Irrigation charge (Rs.)	-0.135	-0.115	-0.055	0.039	0.148*	-0.067	0.079	-0.019
Dummy for RCTs	0.092	0.224***	0.110**	0.164*	1.318*	0.100**	0.132	0.162*
Dummy variable for land holding size	0.102***	0.065	0.008	-0.021	0.004	0.018	0.075	0.065
R^2	0.536	0.445	0.601	0.273	0.994	0.390	0.370	0.518

Figures in parentheses indicate t values.

*,** and***: Significant at 1, 5 and 10 per cent level, respectively.

In case of Central plain agro-climatic zone, the coefficient for seed was found to be positive and significant indicating one per cent increase in expenditure on seed would bring about an increase in gross return by 0.638 per cent. The coefficient for dummy variable of RCTs was found positive and significant suggests that the RCTs adoption has positive impact on gross return.

In case of Western plain and North-eastern plain, the coefficient for dummy variable of RCTs was found positive and significant suggests that the RCTs adoption has positive impact on gross return in both agro-climatic zones.

As regards the human labour the regression coefficient was negative and significant indicating excessive use. The regression coefficient for machine labour, seed, manure and fertiliser and irrigation charges was positive and significant. It implies that there is scope to increase the use of these resources to attain higher return in eastern plain. In Mid-western plain, adoption of rotavator would increase the value of output as coefficient for dummy variable was positive and significant. None of the variables was found significant in Tarai and Bhabar agro-climatic zone. In case of South-western plain zone, coefficients attached to machine labour and seed were negative and significant showing excessive use, whereas the regression coefficient for human labour was positive and significant.

From the above discussion it is clear that both technologies (zero/reduce tillage and rotavator) were found to be beneficial to the farmers for enhancing the value of output. Further it is observed that RCTs are adopted by marginal and small farmers in all the ago-climatic zones except Vindhyan zone. In case of Vindhyan agro-climatic zone, the adoption of RCTs is done only by those farmers having land more than two hectares.

IV

SUMMARY AND CONCLUSIONS

Among the different options of RCTs, farmers in different agro-climatic zones of Uttar Pradesh are adopting and using two technologies, i.e., zero/reduced tillage and rotavator for land preparation and sowing of wheat crop. On an average cost of cultivation of wheat crop was lower for zero/reduce tillage and rotavator adopters as compared to non-adopters. Per hectare wheat yield was higher for zero-tillage and rotavator adopters as compared to non-adopters. Per hectare gross and net return from the wheat under zero-tillage and rotavator was higher than the non-adopters. It was due to higher crop yield and reduction in inputs used in the study area. The economic benefits due to adoption of RCTs were higher in all the agro-climatic zones of Uttar Pradesh. After adoption of RCTs, diesel consumption and carbon emission reduced substantially in the study area. Per hectare irrigation water used for wheat cultivation was lower in case of RCTs adopters as compared to non-adopters. The agronomic and net economic water productivity was higher for RCTs adopters as compared to non-adopters. The estimates suggest that if farmers allocate 25 per cent wheat irrigated area under both the technologies, the incremental wheat yield benefit and irrigation water saving would be 12.74 million quintals and 1011.09 MCM, respectively from eight agro-climatic zones. If farmers of eight agro-climatic zones of Uttar Pradesh allocate 50 per cent their wheat area under both technologies, incremental wheat yield benefit would be 25.47 million quintals and 2022.19 MCM irrigation water saving. From the regression analysis it is clear that both technologies (zero/reduce tillage and rotavator) were found to be beneficial to the farmers for enhancing the value of output. Further it is observed that RCTs are adopted by marginal and small farmers in all the ago-climatic zones except Vindhyan zone. In case of Vindhyan agro-climatic zone, the adoption of RCTs is done only by those farmers having land more than two hectares.

The allocation of 50 per cent wheat irrigated area under both the technology is quite possible after removal of certain constraints in adoption of both technologies. The major constraints associated with the adoption of RCTs were high cost of machine, non-availability of machines on time and higher hiring charges. Thus for the adoption of RCTs on large scale, government should provide more subsidy for the purchase of zero-tillage and rotavator machine.

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